Application of Nonlinear Soil-Structure Interaction in Seismic PRA

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Soil-structure interaction (SSI) analysis is now routinely performed in the seismic probabilistic risk assessment of new and existing nuclear structures. Soil-structure interaction analysis of nuclear structures in the United States is currently performed using linear analyses in the frequency domain using codes such as CLASSI or SASSI, assuming that the in-structure response increases linearly with the ground motion intensity. Nonlinear effects of SSI, which can be significant in beyond-design basis events, are mostly ignored in these calculations. Estimates of seismic hazard at nuclear facility sites have been increasing in recent years as more data is gathered on seismic sources and events, leading to more intense ground motions used for design and performance assessment. Nonlinear SSI effects therefore become more relevant in the seismic probabilistic risk assessment (PRA) of nuclear structures. Nonlinear effects of SSI include material nonlinearities in the soil and the structure, and geometric nonlinearities, namely, gapping and sliding of the foundation.

The study presented in this paper is a part of a larger study to incorporate nonlinear SSI effects in seismic PRA of nuclear structures. The current study involves performing the PRA of a sample nuclear power plant (NPP) structure using traditional and advanced (including nonlinear SSI effects) approaches and comparing the results to examine the effect of nonlinear SSI on seismic risk. Only the effects of gapping and sliding are investigated in the current study. A simple, BWR type NPP structure is chosen along with an idealized soil profile and seismic hazard representative of those at the Advanced Test Reactor (ATR) site at Idaho National Laboratory. The structure is assumed to be surface-founded in order to exacerbate gapping and sliding. The seismic PRA is performed for a real plant system at the ATR site. Realistic probabilistic distributions are assumed for the modulus and damping of the soil, modulus and damping of the superstructure and the coefficient of friction of sliding at the soil-foundation interface. Thirty instances of the SSI model are calculated using Latin Hypercube sampling and the SSI analysis are performed for thirty ground motions at four intensities. The linear SSI analyses are performed using CLASSI and the nonlinear analyses are performed using the commercial finite-element code, LS-DYNA. Preliminary calculations (made from six instances instead of 30) of the seismic fragilities of various components showed a decrease in the conditional probabilities of failure due to the effects of gapping and sliding.